Chapter 3
Sensors and Systems

3-1 Introduction. Remotely sensed data are collected by a myriad of satellite and airborne systems. A general understanding of the sensors and the platforms they operate on will help in determining the most appropriate data set to choose for any project. This chapter reviews the nine business practice areas in USACE Civil Works and examines the leading questions to be addressed before the initiation of a remote sensing project. Airborne and satellite sensor systems are presented along with operational details such as flight path/orbits, swath widths, acquisition, and post processing options. Ground-based remote sensing GPR (Ground Penetrating Radar) is also introduced. This chapter concludes with a summary of remote sensing and GIS matches for each of the nine civil works business practice areas.

a. Industry Perspective on Image Acquisition. In the past 30 years, selection of remotely sensed imagery was confined by system constraints and only provided by a few vendors. Imagery that was available from archive, or that would become available due to orbital frequency, maintained numerous constraints; consequently ground coverage, rather than image resolution, was the primary concern. Additionally, minor consideration was given to the spectral characteristics of the target and the spectral bands available, as there were a limited number of imaging platforms. To an extent projects had to be tailored to fit the limitations of the data. This is no longer the case however, with significant technologic improvements and numerous product choices. Creative researchers are finding new applications in the on-going advancement of remote sensing.

b. Image Improvements. Satellite sensor system developers continue to improve image cost, resolution, spectral band choices, spectral data library sets, and value-added products or post-processing methods. Improvements in sensor development and affordability can be attributed to the commercialization and subsequent expansion of the remote sensing industry. NASA, other US governmental agencies, and foreign space agencies, such as those in Canada, France, India, and Japan, progressively enhance the industry by furthering current technologic advances in the remote sensing field. Consequently, the resolution constraints on data that existed 20 or more years ago are no longer an obstacle with the addition of these affordable higher resolution systems. Listed here are just a few examples of airborne and satellite data costs:

- AVHRR scene at 1 km GSD for < $50
- Landsat TM scene at 30 m GSD for $625
- Landsat ETM scene can be acquired for $800
- ERS-1 SAR scene at 25 m GSD for $2000
- ERS-2 SAR scene at 25 m GSD for $1500.
- Vendors of high-resolution satellite imaging systems products (such as IKONOS or QUICKBIRD or other products with <4 m GSD [ground sampling distance is the spatial resolution measurement]) charge on a per area basis. The minimum area is 11 km^2 for approximately $2000.

c. Archive Imagery. This can be accessed and purchased at a reduced rate. Some imaging systems can acquire new imagery at reasonable rates as well. It is now possible to tailor acquisitions to meet the specific needs of Corps projects. Costs presented in this manual will fluctuate, but generally become more affordable over time. The downward trend in cost applies to all aspects of remote sensing - data acquisition and the required software and hardware.

3-2 Corps 9—Civil Works Business Practice Areas. The spatial, spectral, and temporal requirements set by the goals in a Corps business practice area should be balanced with the economic limits of the project. To achieve this result, it is helpful to consider a few preliminary steps when planning an image data acquisition. Below is a review of the Corps 9 Civil Works Business Practice Areas. The steps that should be taken to determine the specific data requirements follow each business practice. A list of vendor services is presented along with details on the various platforms (airborne, satellite, and ground penetrating radar). The nine business practice areas in Civil Works of the Corps of Engineers and a listing of their operations follows:

a. Navigation.

- Responsible for navigation channels.
- Dredging for specified width and depth.
- Maintenance of 12,000 miles of inland waterways.
- Maintenance of 235 locks.
- 300 commercial harbors.
- 600 smaller harbors.

b. Flood Damage Reduction.

- Build and maintain levees.
- Maintenance of 383 dams and reservoirs.
- Advice on zoning, regulations and flood warning systems.
- Shore protection—protection from hurricane and coastal storms.
- Construction of jetties, seawalls, and beach sand renourishment.
- Responsibility for dam safety—inspection of Corps and other's dams

c. Environmental Missions.

- Ecosystem restoration—many small ecosystem restoration projects, and the larger Florida Everglades hydrologic restoration project.
- Environmental stewardship—protect forest and wildlife habitat; monitor water quality at reservoirs; operate several fish hatcheries; support national goal of "no net loss of wetlands"; and projects on conservation, preservation, restoration and wetland creation.
- Radioactive site cleanup—FUSRAP (Formerly Used Sites Remedial Action Program).

d. Wetlands and Waterways Regulation and Permitting.

- Support Clean Water Act.

- Authority over dumping, dredging and filling in Waters of the US (WoUS).
- Determine areas for protection as wetlands (under guidelines of 1987 Wetland Delineation Manual), and permitting for land use.
- Water supply—Washington DC aqueduct operation, manage water supply from Corps reservoirs and water use for agriculture in arid regions of South-western US
- Hydroelectric power—Corps operates 75 hydroelectric power plants.

e. Real Estate.

- Full range of services to Army and Air Force.
- Manage Contingency Real Estate Support Team (CREST).
- DOD agent for Recruiting Facilities Program, Homeowners Assistance Program and Defense National Relocation Program.

f. Recreation.

- Operate and maintain 2500 recreation areas at 463 lakes.
- Rangers are Dept. of Army employees.
- Corps is active in National Water Safety Program.

g. Emergency Response.

- Response to hurricanes, tornadoes, flooding, and natural disasters.
- Support to FEMA when activated by Federal Response Plan (FRP).
- Under FRP Corps has lead for public works and engineering missions.

h. Research and Development.

ERDC is composed of seven research laboratories for military, civil works and civilian infrastructure applications:

TEC—Topographic Engineering Center
CERL—Construction Engineering and Research Laboratory
CRREL—Cold Regions Research and Engineering Laboratory
WES-GSL—Waterways Experiment Station-Geotechnical and Structures Laboratory
WES-EL—Waterways Experiment Station-Environmental Laboratory
WES-CHL—Waterways Experiment Station-Coastal Hydraulics Laboratory
WES –ITL—Waterways Experiment Station-Information Technology Laboratory

i. Support to Others. This includes engineering and water resources support to state and Federal agencies, and to foreign countries.

3-3 Sensor Data Considerations (programmatic and technical).

a. Below is a list of preliminary steps and questions to consider when planning an image data acquisition. Answer these questions in light of the Corps Civil Works 9 Business Practice Areas before proceeding.

• What is the primary goal of the project?
  Define the problem.
  How can remote sensing be applied to assist in solving the problem?

• What spatial resolution is need?
  Determine the minimum, maximum, and/ or optimal GSD (ground sampling distance).

• What is the target or what is being mapped?
  High-resolution panchromatic (black and white) aerial photography may be sufficient.
  Define what spectral bands are needed.

• Will field work be included in the project budget?
  What detail is needed from the imagery?

• What spectral resolution is needed?
  Set bandwidth and proximity.

• Determine timing and temporal resolution requirements.
  Select season(s) and time frequencies.

• How urgent is the data needed?
  To capture an emergency event or temporal phenomena an airborne system may need to be promptly employed.

• What repeat cycle do we need?
  Each sensor system operates on a different cycle.

• When will ground truth data be collection?
  Image data acquisition ideally coincides with ground truth data collection.

• What are the weather and light conditions?
  Select radar or optical imagery or adjust acquisition timing to accommodate for variable atmospheric conditions.

• What level of processing will be performed by the vendor?
  For example, choose basic processes such as radiometric, atmospheric, and geometric corrections should be considered.

• What accuracy do we want?
  Set vertical and horizontal limits.

• Where is the project geographically located?
  Specify upper left/ lower right hand corner Latitudes and Longitudes.

• What is the funding situation?
Chose a system and methods that will allow you to cost-effectively follow through on a project.

• Do we need new or archived data?
Avoid wasting resources by soliciting imagery data that already exists. Contact TEC Image Office (TIO) to determine image data availability and purchasing procedures.

b. Here are some ancillary decisions to be made based on answers to the above questions.

• What field of view is needed?
Specify image overlap if one image is not sufficient. Be aware that aircraft and flight line paths control image overlap. Should either be altered then the overlap could be negatively affected (Figure 3-1).

• What acquisition look direction?
Radar imagery taken in mountainous regions can have layover distortion and shadow regions; whereas nadir looking airborne imagery has less of that effect, so that equal amounts of backscatter and transmission are collected on both sides of the feature.

• Are commercial analytical services needed?
Will post-processing of the imagery be accomplished in-house, or does this require external expertise — an example is the processing of radar IFSAR into elevation data, which is a very special technique done by dedicated software on dedicated hardware and not generally done in-house. Below are examples of vendor post-processing services.

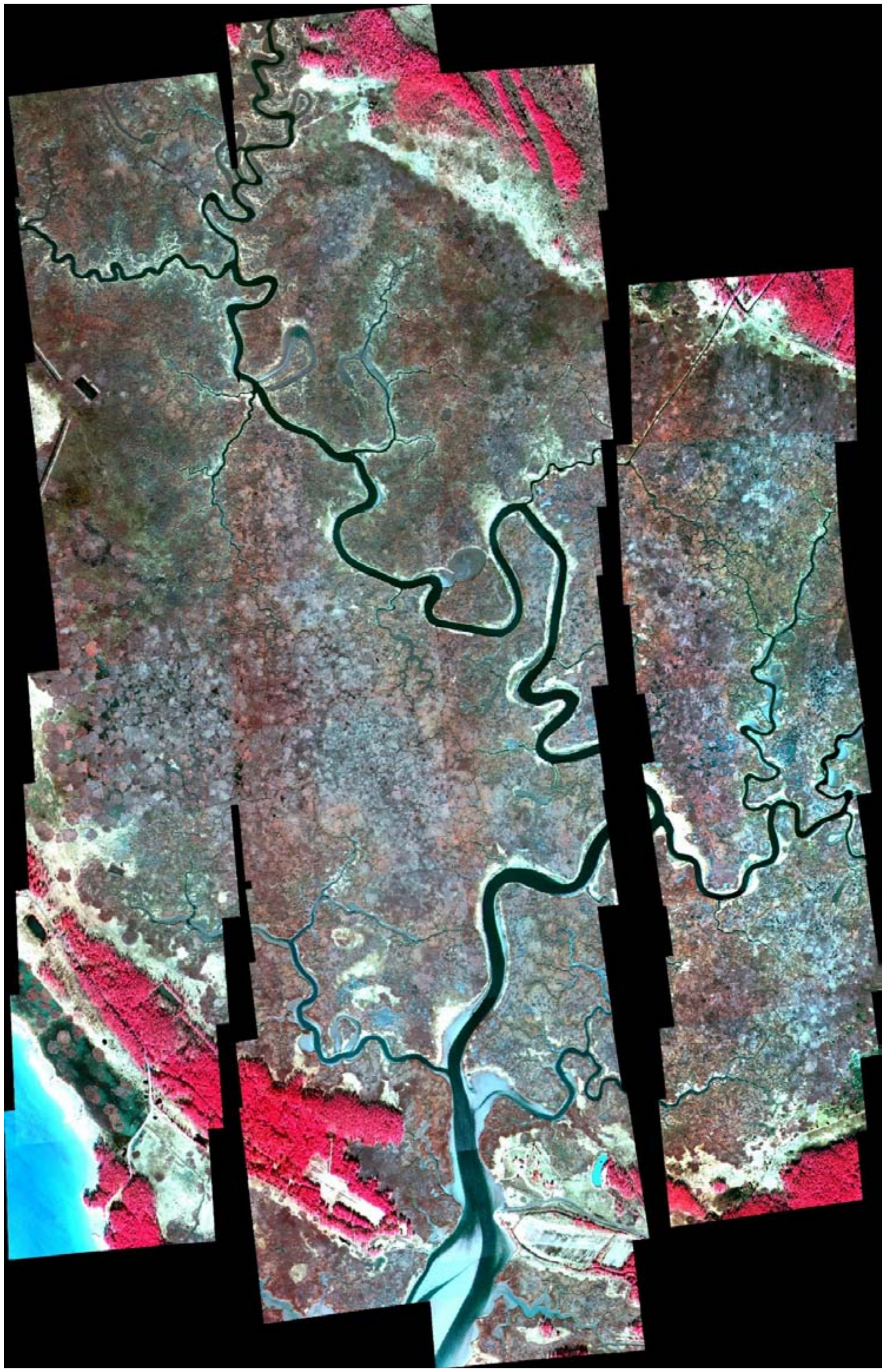

Figure 3-1. In this CAMIS image a decrease in aircraft altitude (due to circumstances beyond the operators control) reduced the pixel size and subsequently decreased the image scene. After mosaicing the individual scenes the side overlaps created "holidays" or gaps in the data. Taken from Campbell (2003).

3-4 Value Added Products. Examples of post-processing done on imagery are listed here with URLs to some of the companies that do the work (sometimes called level 2 or value added products).

- Earthsat Corporation http://www.earthsat.com/ip/prodsvc/ offers geocoding, orthorectification, seamless mosaics, data fusion, and spectral transforms including simulated true color, minimum noise fraction (MNF), vegetation suppression, and decorrelation stretch. They offer hyperspectral processing such as atmospheric correction, automatic endmember selection, pixel unmixing, vegetation stress mapping, and aircraft motion compensation.
- The SPOT Corporation http://www.spot.com/home/proser/welcome.htm offers SPOTView (image map product), land use/land cover (thematic product), elevation/terrain mapping (3-D products), and vegetation products.
- Vectorization Services http://www.vectorizationservices.com/services.htm offers rectification and orthorectification, enhancement, mosaicing, fusion and image interpretation.
- Agricast http://www.agricast.com/ offers value-added products for precision farming, agriculture, and range management.
- Science Applications International Corporation (SAIC) http://www.saic.com/imagery/remote.html offers many value added products for industries from agriculture to utilities. See their web site for the complete list.
- Emerge http://www.emergeweb.com/Public/info/productsPage.asp offers digital ortho products and mosaics from airborne imagery.
- The J.W. Sewall Company http://www.jws.com/pages/core_sevices.html offers photogrammetric mapping, cadastral mapping, municipal GIS development, energy and telecommunications services, and natural resources consulting.
- Analytical Imaging and Geophysics http://www.aigllc.com/research/intro.htm offers analysis of multispectral, hyperspectral and SAR imagery with map production and field verification.
- Spectral International, Inc. http://www.pimausa.com/services.html offers analytical services, consulting and hyperspectral image processing.
- Earthdata http://www.earthdata.com/index2.htm offers digital orthophotos, topographic maps, planimetric maps, and LIDAR 3-D elevation data.
- Intermap Technologies http://www.intermaptechnologies.com/products.htm offers IFSAR DEMs, DSMs, DTMs, and orthorectified radar images.
- 3Di http://www.3dicorp.com/rem-products.html offers LIDAR DEMs, orthorectified imagery, contour mapping, wetlands mapping, vegetation mapping, 3D perspective image drapes, and volumetric analysis.
- Terrapoint http://www.terrapoint.com/Products2.htm offers LIDAR elevation data sets, DTMs, DEMs, canopy DTMs, building heights, land records, and floodmaps.
- i-cubed http://www.i3.com offers information integration and imaging
- Leica Geosystems http://www.gis.leica-geosystems.com offers GIS and mapping.
- PhotoScience, Inc. http:// www.photoscience.com offers aerial photography, photogrammetry, GPS survey, GIS services, image processing

3-5 Aerial Photography. Aerial photography is a highly useful mapping tool and maintains the highest spatial resolution of any of the remote sensing systems. Standard 9-in. (22.9 cm) aerial photos used for mapping and site identification are collected and made available through commercial companies. USGS generates digital elevation model (DEM) data and stereo classification of ground cover from aerial photography. These data are derived from the National Aerial Photography Program (NAPP), formally the National High Altitude Program (NHAP). The NAPP products are quarter quad-centered photographs of the entire contiguous US, acquired every 5 years over 2-year intervals since 1990. NAPP photography is acquired at 20,000 ft (~600 m) above mean terrain with a 6-in. (~15 cm) focal length lens. The flight lines are quarter quad-centered on the 1:24,000-scale USGS maps. NAPP photographs have an approximate scale of 1:40,000, and collect black-and-white or color infrared, as specified by state or Federal requirements. The St. Louis District of the Corps has several airborne contracts in place as well.

a. Softcopy photogrammetry is the semi-automatic processing of aerial photos after they have been digitally scanned into files and transferred into a computer. Once in digital form, the processes of stereo imaging, stereo compilation, aerial triangulation, topographic mapping, ortho-rectification, generation of DEMs, DTMs, and DSMs and digital map generation can be carried out.

b. Aerial photos are geometrically corrected using the fiducial marks and a camera model and projected into the ground coordinates. Images within a stereo overlap are adjusted using a triangulation algorithm so that they fit within the constraints of the ground control point information. At the end of the triangulation, individual stereo models are mathematically defined between stereo images. Topographic information is extracted from the images using autocorrelation techniques that match image patterns within a defined radius. By using parallax created by the different angle shots, elevation is measured from the distance of matching pixels. A terrain model is used to create an ortho-rectified image from the original photo that is precision geocoded and an ancillary Digital Surface Model (DSM) is available.

c. Some of the companies that contract with USACE for aerial photography include:

- Highland Geographic Inc. http://www.highlandgeographic.com
- James W. Sewall Company http://www.sewall.com
- Alcor Technologies Limited http://www.alcortechnologies.com
- Aero-Metric Inc. http://www.aerometric.com
- PhotoScience, Inc. http://www.photoscience.com

3-6 Airborne Digital Sensors. The advancement of airborne systems to include high resolution digital sensors is becoming available through commercial companies. These systems are established with onboard GPS for geographic coordinates of acquisitions, and real time image processing. Additionally, by the time the plane lands on the ground, the data can be copied to CDROM and be available for delivery to the customer with a basic level of processing. The data at this level would require image calibration and additional processing. The data at this level would require image calibration and additional processing. See Appendix F for a list of airborne system sensors.

3-7 Airborne Geometries. There are several ways in which airborne image geometry can be controlled. Transects should always be flown parallel to the principle plane to the sun, such that the BRDF (bi-directional reflectance distribution function) is symmetrical on either side of the nadir direction. The pilot should attempt to keep the plane level and fly straight line transects. But since there are always some attitude disturbances, GPS and IMU (inertial measuring unit) data can be used in post-processing the image data to take out this motion. The only way of guaranteeing nadir look imagery is to have the sensor mounted on a gyro-stabilized platform. Without this, some angular distortion of the imagery will result even if it is post-processed with the plane's attitude data and an elevation model (i.e., sides of buildings and trees will be seen and the areas hidden by these targets will not be imaged). Shadow on one side of the buildings or trees cannot be eliminated and the dynamic range of the imagery may not be great enough to pull anything out of the shadow region. The only way to minimize this effect is to acquire the data at or near solar noon.

3-8 Planning Airborne Acquisitions.

a. Planning airborne acquisitions requires both business and technical skills. For example, to contract with an airborne image acquisition company, a sole source claim must be made that this is the only company that has these special services. If not registered as a prospective independent contractor for a Federal governmental agency, the company may need to file a Central Contractor Registration (CCR) Application, phone (888-227-2423) and request a DUNS number from Dun & Bradstreet, phone (800-333-0505). After this, it is necessary for the contractee to advertise for services in the Federal Business Opportunities Daily (FBO Daily) http://www.fbodaily.com. Another way of securing an airborne contractor is by riding an existing Corps contract; the St. Louis District has several in place. A third way is by paying another governmental agency, which has a contract in place. If the contractee is going to act as the lead for a group acquisition among several other agencies, it may be necessary to execute some Cooperative Research and Development Agreements (CRDAs) between the contractee and the other agencies. As a word of caution, carefully spell out in the legal document what happens if the contractor, for any reason, defaults on any of the image data collection areas. A data license should be spelled out in the contract between the parties.

b. Technically, maps must be provided to the contractor of the image acquisition area. They must be in the projection and datum required, for example Geographic and WGS84 (***World Geodetic System*** is an earth fixed global reference frame developed in 1984). The collection flight lines should be drawn on the maps, with starting and ending coordinates for each straight-line segment. If an area is to be imaged then the overlap between flight lines must be specified, usually 20%. If the collection technique is that of overlapping frames then both the sidelap and endlap must be specified, between 20 and 30%. It is a good idea to generate these maps as vector coverages because they are easily changed when in that format and can be inserted into formal reports with any caption desired later.

The maximum angle allowable from nadir should be specified. Other technical considerations that will affect the quality of the resulting imagery include: What sun angle is allowable? What lens focal length is allowable? What altitude will the collection be flown? Will the imagery be flown at several resolutions or just one? Who will do the orthorectification and mosaicing of the imagery? Will DEMs, DTMs, or DSMs be used in the orthorectification process? How will unseen and shadow areas be treated in the final product? When planning airborne acquisitions, these questions should be part of the decision process.

3-9 Bathymetric and Hydrographic Sensors.

a. The Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS http://shoals.sam.usace.army.mil/default.htm) system is used in airborne lidar bathymetric mapping. The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) is a partnership between the South Atlantic Division, US Army Corps of Engineers (USACE), the Naval Meteorology and Oceanography Command and Naval Oceanographic Office and USACE's Engineer Research and Development Center. JALBTCX owns and operates the SHOALS system. SHOALS flies on small fixed wing aircraft, Twin Otter, or on a Bell 212 helicopter. The SHOALS system can collect data on a 4-m grid with vertical accuracy of 15 cm. In clear water bathymetry can be collected at 2–3 times Secchi depth or 60 m. It does not work in murky or sediment-laden waters.

b. The Corps uses vessels equipped with acoustic transducers for hydrographic surveys. The USACE uses multibeam sonar technology in channel and harbor surveys. Multibeam sonar systems are used for planning the depth of dredging needed in these shallow waters, where the accuracy requirement is critical and the need for correct and thorough calibration is necessary. USACE districts have acquired two types of multibeam transducers from different manufacturers, the Reson Seabat and the Odom Echoscan multibeam. The navigation and acquisition software commonly in use by USACE districts is HYPACK and HYSWEEP, by Coastal Oceanographics Inc. For further information see the web site at https://velvet.tec.army.mil/access/milgov/fact_sheet/multibea.html (due to security restrictions this site can only be accessed by USACE employees).

3-10 Laser Induced Fluorescence.

a. Laser fluorosensors detect a primary characteristic of oil, namely their characteristic fluorescence spectral signature and intensity. There are very few substances in the natural environment that fluoresce, those that do, fluoresce with sufficiently different spectral signatures and intensities that they can be readily identified. The Laser Environmental Airborne Fluorosensor (LEAF) is the only sensor that can positively detect oil in complex environments including, beaches and shorelines, kelp beds, and in ice and snow. In situations where oil contaminates these environments, a laser fluorosensor proves to be invaluable as a result of its ability to positively detect oil http://www.etcentre.org/home/water_e.html.

b. Other uses of laser fluorosensors are to detect uranium oxide present in facilities, abandoned mines, and spill areas that require remediation. See Special Technologies Laboratory of Bechtel, NV, http://www.nv.doe.gov/business/capabilities/lifi/.

3-11 Airborne Gamma.

a. An AC-500S Aero Commander aircraft is used by the National Operational Hydrologic Remote Sensing Center (NOHRSC) to conduct aerial snow survey operations in the snow-affected regions of the United States and Canada. During the snow season (January–April), snow water equivalent measurements are gathered over a number of the 1600+ pre-surveyed flight lines using a gamma radiation detection system mounted in the cabin of the aircraft. During survey flights, this system is flown at 500 ft (152 m) above the ground at ground speeds ranging between 100 and 120 knots (~51 to 62 m/s). Gamma radiation emitted from trace elements of potassium, uranium, and thorium radioisotopes in the upper 20 cm of soil is attenuated by soil moisture and water mass in the snow cover. Through careful analysis, differences between airborne radiation measurements made over bare ground are compared to those of snow-covered ground. The radiation differences are corrected for air mass attenuation and extraneous gamma contamination from cosmic sources. Air mass is corrected using output from precision temperature, radar altimeter, and pressure sensors mounted on and within the aircraft. Output from the snow survey system results in a mean areal snow water equivalent value within ±1 cm. Information collected during snow survey missions, along with other environmental data, is used by the National Weather Service (NWS), and other agencies, to forecast river levels and potential flooding events attributable to snowmelt water runoff (http://www.aoc.noaa.gov/).

b. Other companies use airborne gamma to detect the presence of above normal gamma ray count, indicative of uranium, potassium, and thorium elements in the Earth's crust (for example, Edcon, Inc., http://www.edcon.com, and the Remote Sensing Laboratory at Bechtel, Nevada). The USGS conducted an extensive survey over the state of Alaska as part of the National Uranium Resource Evaluation (NURE) program that ran from 1974 to 1983, http://edc.usgs.gov/.

3-12 Satellite Platforms and Sensors.

a. There are currently over two-dozen satellite platforms orbiting the earth collecting data. Satellites orbit in either a circular geo-synchronous or polar sun-synchronous path. Each satellite carries one or more electromagnetic sensor(s), for example, Landsat 7 satellite carries one sensor, the ETM+, while the satellite ENVISAT carries ten sensors and two microwave antennas. Some sensors are named after the satellite that carries them, for instance IKONOS the satellite houses IKONOS the sensor. See Appendices D and E for a list of satellite platforms, systems, and sensors.

b. Sensors are designed to capture particular spectral data. Nearly 100 sensors have been designed and employed for long-term and short-term use. Appendix D summarizes details on sensor functionality. New sensors are periodically added to the family of existing sensors while older or poorly designed sensors become decommissioned or defunct. Some sensors are flown on only one platform; a few, such as MODIS and MSS, are on-board more than one satellite. The spectral data collected may span the visible (optical), blue, green, microwave, MIR/SWIR, NIR, Red, or thermal IR Sensors can detect single wavelengths or frequencies and/or ranges of the EM spectrum.

3-13 Satellite Orbits.

a. Remote sensing satellites are placed into different orbits for special purposes. The weather satellites are geo-stationary, so that they can image the same spot on the Earth continuously. They have equatorial orbits where the orbital period is the same as that of the Earth and the path is around the Earth's equator. This is similar to the communication satellites that continuously service the same area on the Earth (Figure 3-2).

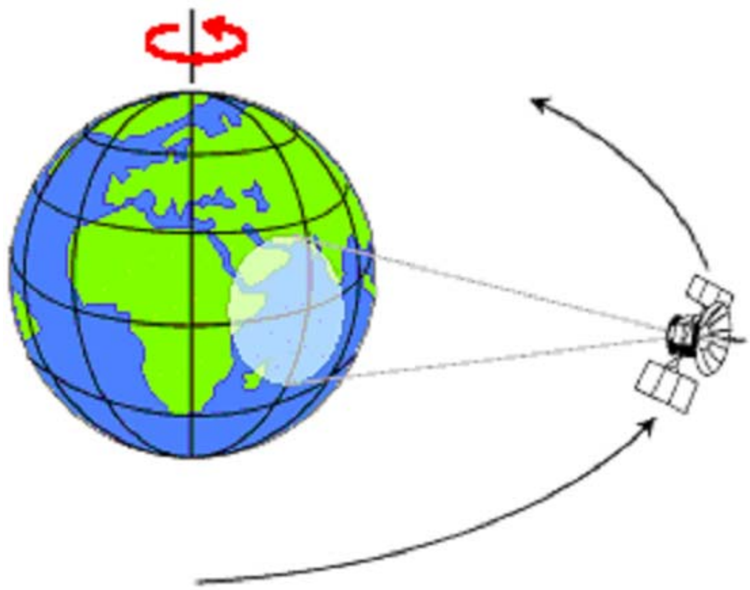

Figure 3-2. Satellite in Geostationary Orbit. Courtesy of the Natural Resources Canada.

b. The remaining remote sensing satellites have near polar orbits and are launched into a sun synchronous orbit (Figure 3-3). They are typically inclined 8 degrees from the poles due to the gravitational pull from the Earth's bulge at the equator; this allows them to remain in orbit. Depending on the swath width of the satellite (if it is non-pointable), the same area on the Earth will be imaged at regular intervals (16 days for Landsat, 24 days for Radarsat).

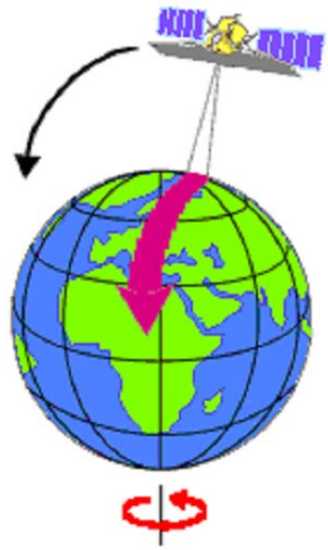

Figure 3-3. Satellite Near Polar Orbit, Courtesy of the Natural Resources Canada.

3-14 Planning Satellite Acquisitions. Corps satellite acquisition must be arranged through the Topographic Engineering Center (TEC) Imagery Office (TIO). It is very easy to transfer the cost of the imagery to TEC via the Corps Financial Management System (CFMS). They will place the order, receive and duplicate the imagery for entry into the National Imagery and Mapping Agency (NIMA) archive called the Commercial Satellite Imagery Library (CSIL), and send the original to the Corps requester. They buy the imagery under a governmental user license contract that licenses free distribution to other government agencies and their contractors, but not outside of these. It is important for Corps personnel to adhere to the conditions of the license. Additional information concerning image acquisition is discussed in Chapter 4 (Section 4-1).

a. *Turn Around Time*. This is another item to consider. That is the time after acquisition of the image that lapses before it is shipped to TEC-TIO and the original purchaser. Different commercial providers handle this in different ways, but the usual is to charge an extra fee for a 1-week turn around, and another fee for a 1 to 2 day turn around. For example, SPOT Code Red programmed acquisition costs an extra $1000 and guarantees shipment as soon as acquired. The ERS priority acquisition costs an extra $800 and guarantees shipment within 7 days, emergency acquisition cost $1200 and guarantees shipment within 2 days, and near real time costs an extra $1500 and guarantees shipment as soon as acquired. Also arrangement may be made for ftp image transfers in emergency situations. Costs increase in a similar way with RADARSAT, IKONOS, and QuickBird satellite imaging systems.

b. Swath Planners.

- Landsat acquired daily over the CONUS, use DESCW swath planner on PC running at least Windows 2000 for orbit locations. http://earth.esa.int/services/descw/
- ERS, JERS, ENVISAT—not routinely taken, use DESCW swath planner on PC running at least Windows 2000 for orbit locations. http://earth.esa.int/services/descw/
- RADARSAT—not routinely acquired, contact the TEC Imagery Office regarding acquisitions of Radarsat data.
- Other commercial imaging systems, contact the TEC Imagery Office regarding acquisitions.

3-15 Ground Penetrating Radar Sensors. Ground penetrating radar (GPR) uses electromagnetic wave propagation and back scattering to image, locate, and quantitatively identify changes in electrical and magnetic properties in the ground. Practical platforms for the GPR include on-the-ground point measurements, profiling sleds, and near-ground helicopter surveys. It has the highest resolution in subsurface imaging of any geophysical method, approaching centimeters. Depth of investigation varies from meters to several kilometers, depending upon material properties. Detection of a subsurface feature depends upon contrast in the dielectric electrical and magnetic properties. Interpretation of ground penetrating radar data can lead to information about depth, orientation, size, and shape of buried objects, and soil water content.

a. GPR is a fully operational Cold Regions Research and Engineering Laboratory (CRREL) resource. It has been used in a variety of projects: e.g., in Antarctica profiling for crevasses, in Alaska probing for subpermafrost water table and contaminant pathways, at Fort Richardson probing for buried chemical and fuel drums, and for the ice bathymetry of rivers and lakes from a helicopter.

b. CRREL has researched the use of radar for surveys of permafrost, glaciers, and river, lake and sea ice covers since 1974. Helicopter surveys have been used to measure ice thickness in New Hampshire and Alaska since 1986. For reports on the use of GPR within cold region environments, a literature search from the CRREL website (http://www.crrel.usace.army.mil/) will provide additional information. Current applications of GPR can be found at http://www.crrel.usace.army.mil/sid/gpr/gpr.html.

c. A radar pulse is modulated at frequencies from 100 to 1000 MHz, with the lower frequency penetrating deeper than the high frequency, but the high frequency having better resolution than the low frequency. Basic pulse repetition rates are up to 128 Hz on a radar line profiling system on a sled or airborne platform. Radar energy is reflected from both surface and subsurface objects, allowing depth and thickness measurements to be made from two-way travel time differences. An airborne speed of 25 m/s at a low altitude of no more than 3 m allows collection of line profile data at 75 Hz in up to 4 m of depth with a 5-cm resolution on 1-ft (30.5 cm)-grid centers. Playback rates of 1.2 km/min. are possible for post processing of the data.

d. There are several commercial companies that do GPR surveys, such as Blackhawk Geometrics and Geosphere Inc., found on the web at http://www.blackhawkgeo.com, and http://www.geosphereinc.com.

3-16 Match to the Corps 9—Civil Works Business Practice Areas. Match to the Corps business practice areas presupposes that everything about remote sensing for a particular ground or water parameter is known or works. However, this is not the case. Mapping for the amount of visible detail for a particular business area can be and has been readily listed in the National Imagery Interpretability Rating Scale (NIIRS). An approximate match between NIIRS level and GSD is given in the following.

a. Navigation Needs—lock and dam modification and construction, harbor facilities construction, channel dredging.

(1) How can remote sensing help in the maintenance, dredging, and planning for new construction?

(2) Remote sensing match:

- Hydrographic surveys creating maps of underwater depth and obstructions.
- Maps of original land and water area to be converted.
- Elevation profiles of the areas.
- Maps of the surrounding area to meet requirement of no net loss of wetlands.
- See Paragraph 3-3.

b. Flood Damage Reduction Needs—levee, dam, jetty, and seawall construction and beach sand re-nourishment projects, installation of flood warning systems.

(1) How can remote sensing help in planning for construction, for beach sand re-nourishment projects, and for the installation of flood warning systems?

(2) Remote sensing match:

- Maps of construction and surrounding areas.
- Elevation profiles of the areas.
- Beach maps and elevation profiles and near shore bathymetry.
- Levee top elevations for flood warning systems.
- See Paragraph 3-3.

c. Environmental Mission Needs—ecosystem restorations, protection of forest and wildlife habitat, water quality monitoring, wetland creation, radioactive and abandoned mine lands (AML) cleanup.

(1) How can remote sensing help in planning for ecosystem restorations, monitoring forest and wildlife habitat and water quality, and for wetland creation and AML cleanup?

(2) Remote sensing match:

- Maps of current ecosystem, wetlands, rivers, streams, aquifers, natural vegetation.
- Maps of forest types and vegetation communities.
- Map chlorophyll and sediments in lakes and reservoirs.
- Map mine sites, polluted drainage and stream and watershed areas.
- See “Sensor Data Considerations (programmatic and technical).”

d. Wetlands and Waterways Needs—authority over dumping, dredging, and filling in Waters of the US, delineate wetlands, monitor water quality of water supplies, planning conservation of water in the arid southwest.

(1) How can remote sensing help in delineating wetlands and issuing permits for dumping, dredging, and filling, monitoring water quality of water supplies, and in management of water in arid and agricultural regions of the west and southwest?

(2) Remote sensing match:

- Maps delineating wetlands.
- Maps of water quality and sedimentation of water supplies.
- Maps of snow/ water equivalency and reservoir capacity and agriculture demand.
- See Paragraph 3-3.

e. Real Estate Needs—locations and types.

(1) How can remote sensing help in planning real estate location and type?

(2) Remote sensing match:

- Mapping urban, suburban and city locations for entry into a GIS.
- see “Sensor Data Considerations (programmatic and technical).”

f. Recreation—maintain 2500 recreation areas.

(1) How can remote sensing help in maintenance and operation of recreation areas?

(2) Remote sensing match:

- Mapping and classification of forests and habitat in parks and monitoring water quality of lakes and reservoirs.
- See Paragraph 3-3.

g. Emergency Response—response to hurricanes and natural disasters.

(1) How can remote sensing help in response to natural disasters?

(2) Remote sensing match:

- Immediate mapping of disaster area.
- High resolution mapping to determine extent of personal damage (houses) and temporary roofing capability (FEMA regulated at 50 % roof rafters still in place).
- See Paragraph 3-3.

h. Research and Development—Seven research laboratories and support to the Nation's civil works sector.

(1) How can remote sensing help in the work carried out by the seven research laboratories and support the nation's civil works sector?

(2) Remote sensing match:

- Mapping and classification in mission areas and specific projects.
- Development of new methods and techniques of remote sensing and processing.
- See Paragraph 3-3.

i. Support to Others—other state and Federal agencies, foreign countries, and reimbursable work done.

(1) How can remote sensing help in work done for other state and federal agencies, foreign countries and in reimbursable work done?

(2) Remote sensing match:

- Mapping, remote sensing and GIS training, and classification in ongoing projects
- See Paragraph 3-3.